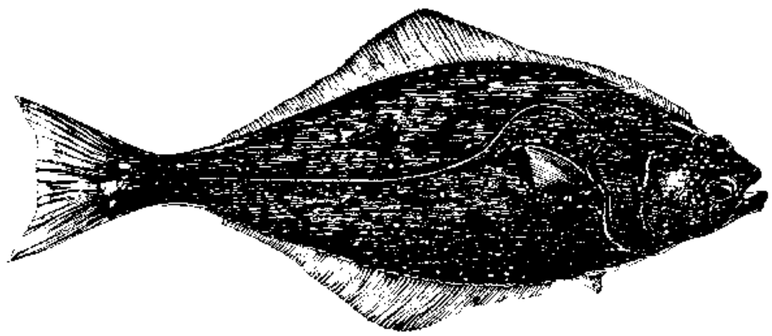

HALIBUT FARMING

Its development and likely impact on the market for wild Alaska halibut

State of Alaska

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and Economic Development

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A report prepared for the
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Foreword

The market dominance of farmed salmon has irrevocably changed the salmon industry in Alaska, as all in the industry are profoundly aware. With farmed halibut on the horizon, it is only prudent to ask the question if farmed halibut will be round two for Alaska's fishing industry. Hence, the reason the Department of Commerce and Economic Development commissioned this report – to give the industry a timely report on the likely production and market implications for wild Pacific halibut. I want to stress that the purpose is not to reignite the debate on fish farming in Alaska. Just like for salmon, there are opportunities to differentiate between farm and wild and to create market synergies or new market niches but first we have to know what to expect. This report represents our first informed glimpse into the future of farmed halibut. With the experience and knowledge of John Forster, this report represents an insider's "heads-up". Read it closely and plan accordingly.

Kate Troll
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About the Author

John Forster has 33 years international experience in commercial aquaculture and related public sector research. While working as a scientist for the British government he conducted some of the first research on feed formulation for farm raised shrimp and gained a doctorate in marine science. In 1974, he joined a subsidiary of BOC Plc where he directed the Company's R&D and built and managed a prototype commercial trout farm which pioneered the use of pure oxygen in aquaculture. Following this he was asked to head a new technical services division which, based on the Company's proprietary technology, provided aquaculture design and consulting services worldwide. During the next five years he was instrumental in starting new aquaculture projects in Chile, Greece, Saudi Arabia, Turkey and the U.S.A., working with species including trout, salmon, tilapia, guilt-head bream and European sea bass.

When one of the leading Norwegian salmon farming companies, Stolt Sea Farm, began its international expansion in 1984, Forster moved to Port Angeles, WA to head its U.S. west coast operations. As president of Stolt Sea Farm Washington Inc. he developed a salmon farming business to over $5 million in sales and guided a sturgeon farming operation in California through its R&D phase to its first production of farm raised caviar. Forster began his own consulting practice in January 1994 through which he provides guidance to public and private sector clients on various aquaculture matters. He is also serves as president and is part owner of Columbia River Fish Farms Inc., which raises steelhead trout in E. Washington.

Forster has served as president of The Washington Fish Growers Association, chairman of the Industry Advisory Committee of the Western Region Aquaculture Consortium and is a board member of the Washington Farmed Salmon Commission.

Summary

Halibut has attributes for farming which make it likely that it will succeed as a farm fish. These include:

- adaptability to farm conditions,
- ability to convert food efficiently into growth,
- resistance to common marine diseases,
- growth to a large size,
- pure white, firm, mild tasting meat with good shelf life,
- high fillet yield, up to 60%.

There are still significant technical hurdles to overcome, however, before large volumes of farmed halibut will be produced. Most countries which have salmon farms now also have development programs for farming of Atlantic species of halibut, *Hippoglossus hippoglossus*. Norway is the world's leading farmed halibut producer, active research and commercial development having been in process there since 1985. Scotland and Ireland also have well advanced halibut hatchery programs and are positioned to catch up with Norway, if the necessary commercial investment is made. There are also active research programs in Canada, Ireland and Chile.

A major technical hurdle and bottleneck for the halibut farming industry is the difficulty of producing juvenile halibut in hatcheries. Halibut larvae are one tenth the size of salmon alevins and much more delicate. Replication of their larval life history under hatchery conditions is a challenge especially as regards feeding. Live food organisms are required by halibut larvae when they first start to feed and the supply of such live foods, obtained either by filtration from sea water, or culture in the hatchery, has been a problem. There are indications that this is now being resolved using nutritionally enriched Artemia (brine shrimp).

Once through the hatchery stage, halibut juveniles are robust and do well under farm conditions. Experience, to date, indicates they are resistant to disease and are able to convert their food into dry weight very efficiently. Both attributes suggest that the costs of on-growing halibut could be quite low once other difficulties are overcome. A substantial challenge in on-growing is whether halibut can be farmed efficiently, like salmon, in floating net pens. This is the simplest and most cost effective way to grow many fish but flat fish like halibut are not well suited to net pens because they prefer to remain on or near the bottom, rather than swim in mid water. The alternative to net pens is on-growing in on-shore tanks. However, such facilities are expensive to build and to operate and it is likely that net pens will become the preferred method once designs for flatfish are perfected.

Data on the costs of halibut farming is still mostly in the form of projections because so little farmed halibut has yet been produced on a commercial scale. Published estimates of production costs range from USD1.85 - USD2.21/lb, live weight. This is before financing costs, which are substantial in halibut farming, because rearing facilities are expensive and a substantial inventory of live fish must be maintained. The investment required is significantly more than it is for salmon because halibut need more rearing space and are slower growing. An important future challenge for the industry is to find ways of reducing this capital requirement.

It is projected that production costs could fall over the next 15 to 20 years to between USD1.02 to USD1.38/lb, if key technical hurdles are overcome. This assumes improvements in hatchery production, feeds and feeding methods and the design of flatfish net pens.

The amount of farmed halibut likely to be sold over the next three years is quite small. Based on the number of juveniles produced in hatcheries from 1996-1998 projected volumes are:

Year	Pounds Produced
1999	1,040,000
2000	2,960,000
2001	6,240,000

Farmed halibut will not be a serious competitor for wild Pacific halibut in the near future therefore. In fact its presence in the market, and the promotional efforts of the farmers who grow it, could stimulate interest in halibut as a seafood category. During the next few years, while volumes of farmed halibut are limited, this could provide an opportunity for marketers of wild, Pacific halibut and it is suggested that, to prepare for this, it would be helpful to research and document the comparative quality attributes of Pacific versus Atlantic halibut.

In the longer term, 15 to 20 years, it is probable that the supply of farmed halibut will exceed landings from the wild fishery. The farmed product will then become the supermarket staple in the same way farmed salmon has become today. Though this may appear to threaten the market for wild, Pacific halibut, there is time to prepare and it could, in fact, present another opportunity. Alaska's salmon industry has shown what can be done with the high quality salmon products by marketing labels of origin, such as Copper River salmon. Pacific halibut is one of the world's highest quality wild fish and it is harvested from a fishery which is predictable and well managed. It would seem that it could enjoy similar success if and when the time comes that farmed halibut becomes the principle commodity.

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1. INTRODUCTION

Interest in the development of halibut farming springs from success in salmon aquaculture. In just 30 years, commercial salmon farming has grown from little more than an experiment to a global industry, producing over 1.5 billion pounds of farmed salmon per year from farms in 15 different countries. In doing so, it has inspired belief in marine aquaculture as a new source of fisheries products and proved to a skeptical seafood industry that marine fin fish aquaculture is for real. At the same time, salmon farmers and the industries who support them have developed a range of competencies which now make it inevitable that more and more of the fish we eat will be grown in farms. Many different fish species are now being examined for their aquaculture potential, among them The Atlantic halibut *(Hippoglossus hippoglossus).*[1]

This report reviews the status and potential of halibut aquaculture and examines its possible impact on the market for wild Pacific halibut *(Hippoglossus stenolpis)*. Its timing, relative to the development of salmon farming, is equivalent to the early 1970's. At that time salmon, itself, was a new aquaculture species, with some 10 to15 years to go before production would increase sufficiently to affect the market for wild Alaskan salmon. Halibut farming in 1999 is at this same early stage. It does not present an immediate competitive threat to wild halibut, nor is it certain that farmed halibut will, necessarily, have a negative impact on the market for wild fish, especially in the short and medium term. What is certain, in this author's opinion, is that marine fin fish aquaculture will continue its world wide expansion and that halibut will succeed as a farm fish because it has attributes that make it well suited for this purpose. These include:

- adaptability to farm conditions,
- ability to convert food efficiently into growth,
- resistance to common marine diseases,
- growth to a large size,
- pure white, firm, mild tasting meat with good shelf life,
- high fillet yield, up to 60%,
- no pin bones.

By comparison with most other candidate species for aquaculture, this is a formidable list. On the negative side, halibut has a difficult larval rearing phase and, as a flatfish, it is not well suited for on-growing in net pens. These are major technical hurdles which halibut farmers, and the researchers who support them, must learn to overcome. The following paragraphs describe their achievements to date and speculate on how this new industry may develop as solutions are found.

2. THE TECHNOLOGY

The challenge in farming any fish is to replicate its life cycle in captivity in a way which is predictable and repeatable, and at a cost which allows it to be sold at a profit. The problem with many marine fish species, as compared to salmonids, is that their eggs are small and the resulting larvae are delicate (See Figure 1, Page 4), having to be fed live feed before they can be weaned onto less expensive and much more convenient formula feeds. A marine fin fish hatchery has to mimic conditions in the ocean and provide a succession of planktonic, live food organisms of adequate

[1] The Atlantic halibut *Hippoglossus hippoglossus* and the Pacific halibut *Hiippoglossus stenolepis* are very similar biologically. Though almost all present research on halibut aquaculture is on the Atlantic species most aquaculture biologists assume that farming techniques for Atlantic halibut will be able to be applied to Pacific halibut.

nutritional value and increasing size to satisfy the growing larvae, until such time as weaning on to formula feeds can be accomplished. For some species, weaning may never be possible, preference always being given to prey which is alive, moist and moving. Others, halibut included, can be weaned and will take dry feeds, but the process is a critical step in a series of critical steps in producing juvenile fish ready for on-growing.

The key stages in halibut aquaculture described below are:

- Hatchery
  - — Broodstock holding and spawning
  - — Egg incubation
  - — Yolk sac larvae development
  - — First feeding
  - — Metamorphosis
  - — Weaning
- Nursery
- On-growing

2.1 Hatchery

The hatchery phase is generally regarded as the major bottleneck in the development of halibut farming. Halibut eggs are about one tenth of the size (volume) of salmon eggs and are adapted for life in deep ocean waters. Both the eggs and yolk sac larvae are especially delicate, compared to other cultivated marine fish, and the yolk sac stage is prolonged (40-45 days at 6°C). At the end of the yolk sac stage, the larval halibut must start to feed, followed by metamorphosis, when the symmetrical larva (shaped like a round fish) changes to become a flatfish. This is then followed by weaning. The whole process to produce a juvenile weighing about 5 grams (one-fifth of an ounce) takes about 150 days.[2] Survival can vary from nothing up to 30-40% in some batches fed with natural copepods, but is usually between 3-10%, if things go reasonably well.

2.1.1 Broodstock and spawning

Up to now, farmers and researchers have obtained halibut eggs from broodstock which are caught in the wild and then ‘conditioned’ in captivity. It can take two or three years before such brood fish will produce a reliable amount of high quality eggs and lack of eggs is a constraint to some research and commercial programs. The natural spawning season for Atlantic halibut is from February - May, but water temperature and light can be varied under culture conditions, so that some fish are ready to produce eggs at all times of the year.[3] Halibut broodstock are usually held in tanks rather than cages, so they can be handled more easily for spawning. Water temperature is usually kept below 8°C and they are mostly fed on a formula feed which is made into moist ‘sausages’ immediately before feeding.[4] Before these feeds were developed, broodstock halibut were fed on raw fish, which did not always provide all the nutrients required and carried with it the risk of transferring disease.

Halibut are portion spawners, meaning that they do not release all their eggs at once. Eggs may be taken up to 15 times from one fish during its spawning cycle, at intervals of 2-8 days. Depending on size, a female can produce from 1-20 liters of eggs in a spawning season, each liter containing about 40,000 eggs at three millimeters in

[2] Holm, J.C., 1997. Juvenile Production of Marine Fish. Aquaculture Trondheim ’97, European Aquaculture Society, Abstracts pp. 34.

[3] Holm, J.C., A Mangor-Jensen and T.J. Hansen, 1995. Recent improvements of farming techniques of Atlantic salmon (*Salmo salar*) and Atlantic halibut (*Hippoglossus hippoglossus*) in Norway. Proc. Of Workshop on the Culture of High-Value Marine Fishes, Oceanic Institute, Hawaii, 1994, pp. 231-240.

[4] Anon., 1997. Otter Ferry halibut on improved diets. Fish Farmer, Sept/Oct, p.53.

diameter.[5] Ripe eggs are stripped from an unanaesthetized female by stroking gently along the ovary towards the genital opening, and are fertilized with milt from one or two males. Normally, it is expected that at least 90% of the eggs will be fertilized and that 75 - 80% of the fertilized eggs will hatch.[6]

Though most, if not all, halibut juveniles produced to date have come from eggs produced by wild caught, captive broodstock, more and more will eventually come from hatchery raised fish. This will create the opportunity for selection and genetic improvement. Stolt Sea Farm is reported to be holding potential broodstock from the offspring of three year classes of hatchery reared fish for this purpose.[7]

2.1.2 Egg Incubation

Once fertilized, eggs are incubated in upwelling incubator tanks in a dark room, because light adversely affects development and hatching. Since they are adapted for life at depths of 1000' and below, it is not surprising that the eggs are negatively affected by light, or that they need a constant, cool incubation temperature of 4-6°C and full strength salinity water. Incubation systems vary but, in Norway, 250 liter (65 gallons) containers are generally used with water flows between 1-2 liters per minute. Dead eggs and debris are removed daily to prevent bacterial and fungal contamination, and live eggs receive a one time disinfection immediately before hatching. Under these conditions, hatching occurs after about 14 days with the emergence of a delicate yolk sac larva, which is between 6-7mm long and has a large yolk sac, but no functional eyes or mouth (See Figure 1).[8]

2.1.3 Yolk sac larvae development

The yolk sac stage lasts for up to 50 days. Since the larvae are not usually started on feed until around day 35-40, this means that for the first 35-40 days they must live and develop entirely from their yolk reserves. This may seem similar to the early life of salmonids, but the similarities are superficial. While salmonid yolk sac stages are adapted to a life in gravel and sand with high bacterial loads and an abrasive environment, the 'bathypelagic' halibut larvae are adapted to very stable physical conditions with no abrasion and low levels of micro-organisms.[9] Creating these conditions under artificial culture has been one of the challenges of halibut larval rearing. In Norway, it is usually done by holding the larvae in silo shaped tanks up to 15,000 liters in volume (4000 gallons) with an inflow of new water at the bottom and an outflow at the top. Floating plastic bags have also been used in the same way. In Scotland, much smaller tanks are used, ranging in volume from 500 - 2,000 liters. This facilitates temperature control and is better suited to smaller egg batches obtained from UK stock.[10] Water temperature is maintained between 7-9°C and the fish are kept in darkness, since they are 'phototactic' at this stage and will swim towards any light source.[11] [12]Survival during the yolk sac stage generally ranges between 50-70% and the larvae grow from 6 to 12 millimeters long.

2.1.4 First feeding

For first feeding the larvae are transferred to shallow, illuminated circular tanks. They are removed from their silos by drawing them to the top with light and scooping them out with buckets. Water temperature in the first feeding tanks is increased to 12°C,

[5] Pittman, K. Rearing Halibut in Norway: Present Practices and Challenges. Mar. Freshwater Res., Vol. 47, pp.243-249.

[6] Olsen,Y., 1988. Status of the Cultivation Technology for Production of Atlantic Halibut (*Hippoglossus hippoglossus*) juveniles in Norway / Europe. Aquaculture, in press.

[7] Anon., 1996. Stolt moves on with turbot and halibut. Fish Farmer, vol. 19, No. 5, pp.20-22.

[8] Brown, J. A. and T. Keough. 1994. Atlantic Halibut [culture]. Bull. Aquacult. Assoc. Can. No.94-1, pp.9-12.

[9] Huse, I., 1988. Culture of Halibut. Proceedings of Aquaculture International Congress, Vancouver, B.C., pp. 481- 484

[10] Shields, R.J. and J.S. Gillespie, 1998. A UK perspective on intensive hatchery rearing methods for Atlantic halibut. World Aquaculture Society, Aquaculture '98, Book of Abstracts, p. 488.

[11] Pittman, K. Rearing Halibut in Norway: Present Practices and Challenges. Mar. Freshwater Res., Vol. 47, pp.243-249.

[12] Wray, T., 1998. Honing in on halibut. Fish Farming International, February 1998, pp. 52-56.

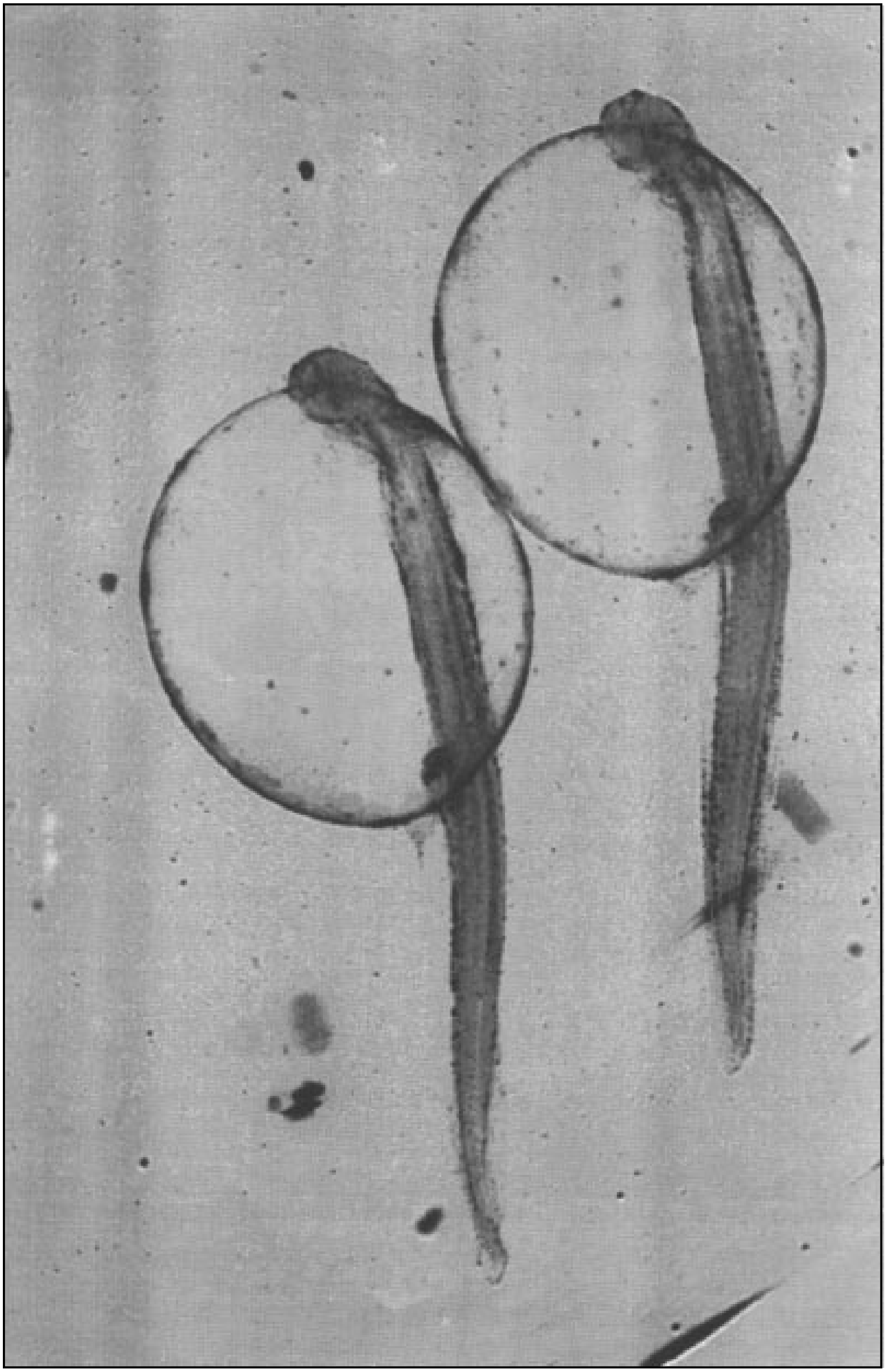

Figure 1 Halibut yolk sac larvae, newly hatched.
(Photo courtesy of Mike Rust, NMFS, Seattle)

over three days, and the larvae are fed with *Artemia* (brine shrimp), hatched from desiccated eggs, and/or copepods captured by filtration from natural sea water. In some cases, cultured, live *Rotifers* are fed for the first few days in addition to *Artemia,* because they are smaller.

The quality of these live feeds is the subject of much research. *Artemia* are an incomplete source of nutrients and have to be supplemented by wild caught copepods, or by enrichment mixtures on which the *Artemia* feed before being fed to the halibut larvae. The incomplete nutrition provided by unenriched *Artemia* causes low survival, incomplete metamorphosis and/or abnormal pigmentation which, in the latter case, compromises the value of the fish when they are sold.

Some of the early Norwegian success in rearing halibut juveniles was achieved because researchers used mainly wild caught copepods for feed. Though these provide an excellent balance of nutrients, their collection is expensive, unpredictable and seasonal, making the process inherently unreliable and difficult to scale up. Scottish and Icelandic researchers, on the other hand, have always focused on a more ‘intensive’ approach to larval feeding using *Artemia,* enriched as necessary. This technology is more difficult to perfect, but is potentially more reliable and easier to commercialize. Some Norwegian hatcheries are now switching to this approach. [13] In 1998, a commercial hatchery in Scotland had success by feeding artificially cultured copepods to larval halibut. These copepods were grown using a process pioneered by a Danish company and may prove to be an alternative to *Artemia*.[14]

The timing of first feeding has also been the subject of much investigation. Physiologically, the larvae appear to be ready to begin feeding after about 20 days, or half way through the yolk sac stage. However, it is usual practice to keep them in darkness and not introduce feed until later. This is because it is difficult to avoid the introduction of pathogens with live feed, against which the yolk sac larvae have poorly developed defenses. Average survival, if first feeding goes well, should be about 50% from the end of the yolk sac stage.

2.1.5. Metamorphosis

Flatfish start their lives upright, like a round fish, but at metamorphosis they turn on to one side which then becomes the belly. The eye and nostril on that side then move up and over the head and join the other eye and nostril on what now becomes the back. This extraordinary biological change usually occurs around 90 days after hatching, depending on the rate of larval growth.[15] Not all larvae metamorphose at the same time and, since those that are metamorphosing must be transferred to smaller, flat bottomed tanks in order to complete the process, it is necessary to dip net them out individually. This is labor intensive and research into ways to synchronize metamorphosis is a priority.

2.1.6. Weaning

Weaning occurs when the diet of the newly metamorphosed juveniles is changed from live feed to formula feeds. During this process the young fish, weighing between 250-300 milligrams, are offered both types of feed, with the supply of live feed being gradually reduced. For weaning, the water temperature is increased to 13-14°C,

[13] Shields, R.J. and J.S. Gillespie, 1998. A UK perspective on intensive hatchery rearing methods for Atlantic halibut. World Aquaculture Society, Aquaculture ’98, Book of Abstracts, p. 488.

[14] Anon., 1998. Shift towards halibut. Seafarm Business Review, 08.31.98.

[15] Pittman, K. Rearing Halibut in Norway: Present Practices and Challenges. Mar. Freshwater Res., Vol. 47, pp.243-249

which has been shown to be optimum for growth of young halibut. This process is usually complete in about 30 days, by which time the fish weigh about one gram (0.035 ozs). Expected survival is about 70%.[16]

As presently practiced, weaning is a somewhat cumbersome process and is expensive because the young, growing fish require large amounts of live feed until they are weaned. There is a clear need to reduce the live feed required and recent research on what is called 'co-feeding', where live feed and tiny manufactured feed particles are fed in combination to larvae before metamorphosis, has produced encouraging results.[17] This helps the young fish learn to take inert food early and provides a means to offer supplemental nutrients which may be lacking in the live feed. With this technique it is claimed that fish can be weaned at a weight of 150-200 mg with 90% survival.[18] It is a good example of how marine fish larval rearing methods can and will be made better and less costly in the years ahead.

2.2 Nursery

Once weaned the young halibut grow quickly through a 'nursery' stage. If optimum temperatures are maintained, they will reach a weight of 5-10 grams about 150 days after hatch and 150-200 grams (0.33-0.44 lbs) by the end of their first year. This is an ill-defined stage as regards length of time, or fish size at the end, because the purpose is to hold and grow the young halibut until they can be moved, or sold, to an on-growing system, and the size at which such transfer occurs can vary substantially. For example, if the young halibut are to be on-grown in cages, it is usually thought necessary to grow them in the nursery to 250 - 500 grams (0.5-1.0 lb). On the other hand, if they are to be on-grown in land based tanks, transfer can be made much earlier at, say, 10-20 grams.

Up to a weight of about 10 grams, the young fish are still very vulnerable to disease. *Vibrio* and IPN (infectious pancreatic necrosis), both of which also affect salmon, have caused particular problems.[19] [20]Vaccines can now be used to provide some protection and, once past this stage, halibut are reported to resist diseases well because they have very effective immune systems.[21]

It is well established that in order to optimize growth and to get young halibut off to a 'good start', water temperature should be maintained above 10°C, until the fish weigh about 500 grams. Depending on location, different strategies will be used in halibut hatcheries, individually or in combination, to maintain optimum growing temperatures during the nursery stage. They include:

a. Pumping of natural sea water, when the local temperature regime is 'close enough'. This may include pumping from different depths and mixing as required.
b. Direct heating of sea water using heat pumps, with heat recovery on the outflow using a heat exchanger.
c. Use of industrial waste heat, or 'thermal effluents'. In Iceland, an alternative is to pump geothermally heated sea water.
d. Recirculation systems in which the heated culture water is reused, after it is treated to remove solid wastes and other products of fish metabolism.

Recirculation systems may eventually become the method of choice. Their use for the production of Atlantic salmon smolts in fresh water is becoming increasingly routine,[22]

[16] Pittman, K. Rearing Halibut in Norway: Present Practices and Challenges. Mar. Freshwater Res., Vol. 47, pp.243-249

[17] Rosenlund, G., J. Stoss and C. Talbot, 1997. Co-feeding marine fish larvae with inert and live diets. Aquaculture, No. 155, pp. 183-191.

[18] Roselund, G., 1996. Manufactured feeds for flatfish. Fish Farmer, Vol. 19, No. 5, p.31.

[19] Pittman, K. Rearing Halibut in Norway: Present Practices and Challenges. Mar. Freshwater Res., Vol. 47, pp.243-249

[20] Anon., 1996. Otter Ferry set to launch new halibut hatchery. Fish Farmer, Vol. 19, No. 5, p. 23.

[21] Anon., 1997. First UK harvest of halibut could signal the way ahead. Scottish Fish Farmer, No. 110, p.4-5.

[22] Anon., 1998. Scots build 'world's biggest' smolt unit. Fish Farming International, Vol. 25, No. 8, p. 12.

and salt water recirculation systems are now being perfected for the cultivation of certain high value marine fish.[23] [24]In this author's opinion, such systems will not be competitive, in the long run, with net pen farming methods for production of market ready fish, but they may turn out to be ideally suited for rearing juveniles which, on a per unit weight basis, are more valuable. An interesting development in this field, which promises to reduce the capital cost of recirculation systems, is the use of extremely shallow raceways as holding tanks. Several marine fish species have been shown to do well in these raceways and, since they can be stacked, or tiered, in racks, water reuse from level to level is made simple and the floor area required to accommodate the whole system is reduced.[25]

2.3 On-growing

This appears to be the simplest step in the rearing process from the point of view of biological difficulty. But it is also the step where the most time and money is spent in fish farming and the difficult thing, in on-growing, is to be able to do it profitably. As described below, it is during the on-growing phase that many of the attributes of halibut for aquaculture will have the greatest impact.

2.3.1 Adaptability to farm conditions

Halibut are naturally docile and not easily agitated. As a result, they subject themselves to little stress under farm conditions and, therefore, do better than more excitable species. They also tolerate crowding well, though, as flatfish, they do not fully use the water column as do round fish like salmon. In fact, stocking densities for halibut are usually expressed in terms of kilograms per square meter, rather than kilograms per cubic meter, as they are for round fish. Engelsen[26] provides recommended optimal stocking densities for halibut (Table 1) which, at the higher levels, mean that the fish stack two or three deep on the bottom of the rearing container. This does not appear to stress them and, in this respect, they are similar to other cultivated flatfish such as the European turbot and Japanese hirame.

Table 1. Recommended maximum stocking densities for halibut (Englesen 1995)

Fish weight, (grams)	Density (kg per square meter)
2-149	10
149-448	20
448-1495	30
1495-2496	40
2496-4264	50
4264-6410	60
6410 +	70

A consequence of their bottom dwelling preference is that rearing containers must provide sufficient bottom area, rather than volume, and this makes them more costly. For salmon, rearing volume has become quite inexpensive in recent years as farmers have learned to use larger cages with deeper nets. For halibut, increased depth provides little benefit, so this simple, low cost way of providing additional rearing space is not an option.

[23] Anon., 1998. German pioneers plan turbot farm. Fish Farming International, Vol. 25, No. 8, p. 14.

[24] Blanquet, D and E. Lyngren, 1997. Cultivation of marine fish in closed raceway systems. Aquaculture Trondheim '97, European Aquaculture Society, Abstracts pp. 34.

[25] ∆iestad, V., 1998. Shallow Raceway as a Solution to compact Resource-Maximizing Farming Procedure for Marine Fish Species. Marine Fish beyond the Year 2000: Technological Solutions for Biological Challenges. ICES, C.M.1998/L:2, 11pp.

[26] Englesen, R., 1995. Economical view on halibut on-growing (in Norwegian). In Kveite - fra forsning til naering (*Halibut - from R&D to industry)*. Pitman, K., A.G. Kjorrefjord, L. Berg and R.Englesen, eds), Stiftelsen Havbrukskunnskap, Bergen, pp. 179-198. *(cited in Roselund, G. ARC, Nutreco. Internal memo.)*

One of the big questions, presently, is whether or not halibut on-growing is better done in net pens or in on-shore tanks or raceways. Even though, because of the need to provide more bottom area, net pens for halibut will be more costly than they are for salmon, they are still likely to be considerably less expensive than on-shore systems, where there are substantial costs for tanks, sea water intakes, pumps, etc., as well as for electricity and other inputs to run them. The issue is whether or not the opportunity to control temperature in such systems, and to monitor feeding more closely, provides advantages which justify the higher costs (see Sections 4.2.2 and 4.2.6). For salmon, it has now been well demonstrated that it does not, as evidenced by a number of failed on-shore salmon farms. For flatfish, the balance of advantage may be different. The commercial production of other flatfish species, such as turbot in NW Spain and hirame in Japan and S. Korea, is almost all done on-shore. Most commercial production of halibut, to date, has similarly come from an on-shore unit operated by Stolt Sea Farm. Other producers in Norway, however, and also in Scotland are seeking to on-grow halibut in net pens, in which they do quite well as long as the bottom is solid, or stretched taut, and movement, due to waves and currents, is restricted.

The optimum temperature for growth in halibut varies with size between quite narrow ranges (Table 2)[27]. They do not grow at temperatures below 4°C and larger fish have a low tolerance to water temperatures above 14°C, according to Engelsen.[28] A major kill of farmed halibut apparently occurred in 1997 when water temperatures at a net pen farm at Austevoll, Norway exceeded 18°C. For net pen farms this will limit the number of places where halibut can be most efficiently on-grown, lending further support to the idea that on-shore systems are the best way to do it.

Table 2. Optimum temperature ranges for the growth of halibut at different sizes (Englesen, 1995)

Fish weight in grams	Temperature °C
2-25	11-14
25-100	11-13
100-500	10-12
500-1000	9-11
Above 1000	7-11

The 'debate' about the relative merits of on-shore systems versus net pens is likely to continue for some time, but in this author's opinion, net pens will ultimately prove most cost effective. Apart from cost, a major potential advantage of net pen production is the extent to which halibut farming can be developed as a complimentary activity with existing salmon farms. This will affect both the speed and scale of development and facilitate the rapid uptake of juveniles as they become available, enabling salmon farmers to spread risk and use their resources more efficiently.[29]

2.3.2 Feeding

Halibut take dry, formula feeds well and convert them efficiently in to body weight. This is measured as 'food conversion efficiency' (FCR), which is a ratio calculated by dividing the weight of food fed by the weight gain it yields. There are a number of studies on halibut where this has been found to be less than 1:1; even at this early stage in the development of the technology, when knowledge of halibuts' nutritional needs is still rudimentary.[30] [31] [32]This may be due to an intrinsic virtue of halibut metabolism, or due to a sedentary life

[27] Englesen, R., 1995. Economical view on halibut on-growing (in Norwegian). In Kveite - fra forsning til naering (*Halibut - from R&D to industry)*. Pitman, K., A.G. Kjorrefjord, L. Berg and R.Englesen, eds), Stiftelsen Havbrukskunnskap, Bergen, pp. 179-198. *(cited in Roselund, G. ARC, Nutreco. Internal memo.)*

[28] Cited in: Nova Scotia Department of Aquaculture and Fisheries, 1998. Nova Scotia Aquaculture: Comparative analysis of development issues and species economic potential.

[29] Sutherland, R., 1997. Review of the economics of potential systems for farmed production of Atlantic halibut. Aquaculture Europe (magazine of the European Aquaculture Society), Vol. 21, No. 4, pp.6-11.

[30] Tuene, S and R. Nortvedt, 1995. Feed intake, growth and feed conversion efficiency of Atlantic halibut, *Hippoglossus hippoglossus* (L.). Aquaculture Nutrition, Vol. 1, pp.27-35.

[31] Aksnes, A., Hjertnes, T and J. Opstveldt, 1996. Effect of dietary protein level on growth and carcass composition in Atlantic halibut (*Hippoglossus [¡ppoglossus* L.). Aquaculture, Vol. 145, No. 1/4, pp. 225-233.

[32] Roselund, G., 1996. Manufactured feeds for flatfish. Fish Farmer, Vol. 19, No. 5, p.31

style, or both, but if these excellent FCR's can be achieved in large scale commercial production, it will provide halibut farmers with a significant cost advantage. By comparison, the most efficient salmon farmers rarely achieve 1:1, even after many years of development of feed formulations and feeding techniques.

Another advantage of halibut, compared to salmon, is that there is no need to add carotenoid pigments to the feed to induce red meat color. In salmon feeds such pigments add 12-15% to the feed cost, which adds six to seven cents a pound to the finished weight of salmon produced.

2.3.3 Resistance to disease

To date, there have been few health or disease problems in halibut on-growing units, from which it is inferred that they have a well developed immune system. This is encouraging, but it is still early days in the commercial development of halibut farming and it would be surprising if disease problems did not occur at some stage. If they do not, it is a major advantage of the species. If they do, halibut farmers will be able to draw on the extensive health management expertise which is now available in the farmed salmon industry. Based on numbers provided by Englesen,[33] survival of at least 80% can be expected during the grow out phase which, for a fish at such an early stage in its domestication, is impressive.

2.3.4 Growth to a large size

By comparison with many farmed fish, halibut have the potential to grow to a large size, which helps defray the cost of juveniles. However, there are limits to how large they will be grown in farms because growth and food conversion efficiency are negatively affected by sexual maturation which, under present farm conditions, occurs at about 5-6 pounds in males and 15-20 lbs in females.[34] In some situations it could make sense to grow fish beyond these sizes, for example, if juveniles continue to be scarce and if a premium price is paid for larger fish, **but it is generally assumed, at present, that farmed halibut will be sold in the 5-20 lb size range, and mostly between 5-15 lbs.**

Halibut also grow quite quickly. Table 3 shows growth data summarized by Englesen, based on information from different trials in Norway.[35] The growth rate is not as fast as salmon which, today, can reach 10-12 lbs in 24-27 months at optimum water temperatures. But this is after almost 30 years of development and genetic improvement. The growth rate of farmed halibut will almost certainly be accelerated as experience is gained.

Table 3 Growth rate of farmed halibut (Englesen, 1995)

Months after hatch	Weight in lbs - females	Weight in lbs - males
12	0.33	0.33
18	1.6	1.6
24	3.3	3.3
30	5.5	5.5
42	14.1	10.0
54	28.0	15.5

[33] Englesen, R., 1995. Economical view on halibut on-growing (in Norwegian). In Kveite - fra forsning til naering (*Halibut - from R&D to industry)*. Pitman, K., A.G. Kjorrefjord, L. Berg and R.Englesen, eds), Stiftelsen Havbrukskunnskap, Bergen, pp. 179-198. *(cited in Roselund, G. ARC, Nutreco. Internal memo.)*

[34] Roselund, G. ARC, Nutreco. Undated Internal memo.

[35] Englesen, R., 1995. Economical view on halibut on-growing (in Norwegian). In Kveite - fra forsning til naering (*Halibut - from R&D to industry)*. Pitman, K., A.G. Kjorrefjord, L. Berg and R.Englesen, eds), Stiftelsen Havbrukskunnskap, Bergen, pp. 179-198. *(cited in Roselund, G. ARC, Nutreco. Internal memo*

2.3.5 Fillet yield

Halibut have a high fillet yield, an attribute that has no effect on the costs of on-growing but a great deal to do with the value of the fish when it is grown. It is reported that farmed halibut can be up to 50% thicker than wild halibut with fillet yields up to 60%, compared to wild fish at an average of 52%.[36] [37]Stolt Sea Farm claim a minimum yield of 60% from the farmed halibut they sell.[38] These yields of both farmed and wild halibut are high by comparison with many other fish species. For example farm raised catfish yield about 40-43% and Tilapia yield only 30-33%. This is a critically important and often overlooked characteristic of candidate species for aquaculture which, in the case of halibut, ranks it up with salmon as one of the highest yielding of all species.

3 THE MAJOR PLAYERS

Everywhere salmon farms have been developed there is interest in the possibility of halibut farming. The reasons are straightforward. Halibut require roughly the same water temperatures as salmon in order to grow well and, with the decline in salmon prices, salmon farmers are tempted to 'look over the fence' at a new species which might be sold for more than they are now getting for their salmon. Moreover, where there are salmon farms, there is also considerable fish farm infrastructure and expertise, which will expedite the development efforts. And while many new species do not justify the hype accorded to them by promoters, the attributes listed above suggest that the enthusiasm for halibut is justified.

This section describes some of the work that is in progress in different countries. A list of some of the main public sector research establishments, and commercial producers of farmed halibut in these countries, is provided in Appendix 1. It is not complete, but it does identify the most important centers of expertise and shows the breadth of interest which there is in this new sector of the aquaculture industry.

3.1 Norway

The first larval rearing experiments with halibut were undertaken in 1974, though this work yielded little until 1980, when three halibut fry were produced in floating plastic bags in Flodevigen, Norway. These all died before being weaned and it was not until 1985 that the first two halibut fry, from eggs produced by a captive broodstock, were weaned on to artificial diets. This was achieved following the establishment of two captive halibut broodstocks in 1982 and 1983 at the Aquaculture Research Station of Norway's Institute of Marine Research, Austevoll, and proved ,at last, that it could be done. In 1986 more than one hundred juveniles were produced at Austevoll and, by 1988, several private companies had started to experiment with halibut, leading to production in that year of about 2,000 juveniles.[39]

By 1993 production was up to 170,000 juveniles, followed by 350,000 in 1994. In 1995 and 1996, the industry suffered set backs as larval health and feeding problems reduced production to less than 100,000 juveniles in each year.[40] 1997 saw production recover to 300,000 [41] and it was expected that production would exceed 600,000 in 1998.[42] Recent information suggests that it will, in fact, be less than this, perhaps as low as 400,000,[43] but official numbers are not yet available.

[36] NHH and PA Consulting, 1992. Market Evaluation of Farmed Halibut. A NTNF, Stolt Sea Farm A/S and T. Skretting A/S/BP Nutrition Aquaculture Project.

[37] Crapo, C. and J. Bagette, 1988. The fillet yield for Pacific halibut is 48-60% according to Recoveries and Yields from Pacific Fish and Shellfish. Sea-Grant, Alaska.

[38] Anon., 1996. Stolt moves on with turbot and halibut. Fish Farmer, vol. 19, No. 5, pp.20-22.

[39] Huse, I., 1988. Culture of Halibut. Proceedings of Aquaculture International Congress, Vancouver, B.C., pp. 481- 484

[40] Olsen,Y., 1988. Status of the Cultivation Technology for Production of Atlantic Halibut (*Hippoglossus hippoglossus*) juveniles in Norway / Europe. Aquaculture, in press.

[41] Anon., 1997. Twice as many as last year. Seafarm Business Review, 10.23.97.

[42] Anon., 1998. New halibut record. Seafarm Business Review, 08.18.98.

[43] Finn Christian Skjennum personal communication

To a significant degree the development of halibut farming in Norway was stimulated by the commitment of one company, Stolt Sea Farm, who began a major commercial R&D program in 1988. The Company is now by far the world's leading producer of farmed halibut with sales, in 1997, of 264,000 pounds[44] out of total Norwegian sales of 304,000 pounds.[45] The fish sold by Stolt Sea Farm in 1997 were from the 1993 generation and weighed 9-20 pounds, which is larger than the 5-11 pounds targeted by most halibut farmers , and represents one year's additional growth.[46] It is reported that Stolt Sea Farm is now making a profit on halibut after almost 10 years of investment,[47] but, in announcing its annual results for 1997, it attributed most of its loss, of 76 million NOK (about $11 million), to halibut production. The explanation, presumably, is that current operations are profitable, but that earlier R & D expenses were written off in 1997.

Stolt Sea Farm's pioneering work has encouraged a number of new halibut farming ventures and by the end of 1997 there were about 20 farms producing halibut in Norway.[48] Some newly announced ventures have ambitious goals. For example, a company called Norway Marine Culture A/S recently announced the start of construction of a new, land based halibut farm. This will draw heated (cooling) water from the Norwegian State Oil Company's (Statoil) methanol plant to create optimum growing conditions for young fish.[49] Four or five years from now, the installation is expected to be producing 700,000 large halibut juveniles per year, which will be sold to net pen operators for on-growing to market size.

Stolt Sea Farm's commercial leadership has also been instrumental in stimulating an intensive research effort by various Norwegian research institutes and universities. Even though Norway is deeply committed to the idea of marine aquaculture, it is doubtful if public funds would have been made available so readily without the obvious will of private industry to apply the technology commercially. It has been estimated that the combined investment in halibut research by Norwegian private companies and public sector institutions, up to 1986, was over USD90 million (60 million GB pounds).[50] Some estimates put current expenditure at USD20 million per year,[9] an impressive demonstration of the belief that Norwegians have in this industry and their vision for it.

The leading research station in Norway is the Austevoll facility mentioned above where research on halibut has been going on since the early '80's. Work at Austevoll covers all phases of the halibut's life cycle, with emphasis on broodstock management and egg quality, larval rearing and development of methods for on-growing halibut in sea cages.[51] Another key center for research is the Institute of Aquaculture Research, (AKVAFORSK) at Sunndalsora. This research station leads Norway's successful genetic improvement work on Atlantic salmon. It has now started a program with Atlantic halibut and anticipates cumulative genetic improvements up to 10 -15% per generation.[52] Because it takes four to five years for a female halibut to mature and at least two years for the males, it will take many years before significant genetic gains are achieved, but a start has been made which will unquestionably pay dividends in years to come. There are also several other institutes, contract research organizations and universities which conduct research on halibut aquaculture in Norway and these are listed in Appendix 1. Many of them focus specifically on larval nutrition and health matters.

3.2 United Kingdom

The UK ranks second behind Norway, as regards development effort on halibut farming, and almost all the activity is in Scotland. Only one facility is located elsewhere, a

[44] Anon., 1998. Deficit for Stolt Sea Farm. Seafarm Business Review, 08.10.98

[45] Federation of European Aquaculture Producers. Web site.

[46] Urch, m., 1997. Halibut hits the spot. Seafood International, September, pp. 83-84.

[47] Anon., 1997. Now profiting on halibut. Seafarm Business Review, 08.10.97.

[48] Nova Scotia Department of Fisheries and Aquaculture, 1998. Nova Scotia Aquaculture: Comparative analysis of development issues and species' economic potential.

[49] Anon., 1997. New company to sell large halibut juveniles. Seafarm Business Review, 09.02.97.

[50] Anon., 1997. Scotland's first sales of halibut. Fish Farmer, Nov/Dec., p. 5. (*Cites a paper presented by Joe McDonald at the 1996 Scottish Fish Farming Conference*).

[51] Wray, T., 1998. Honing in on halibut. Fish Farming International, February 1998, pp. 52-56.

[52] Rye, M. and T. Refstie, 1997. Genetic improvement in cultured aquatic species. Aquaculture Trondheim '97, European Aquaculture Society, Abstracts pp. 90-91.

commercial hatchery in the Isle of Man. The research has been leading, since 1983 by the Seafish Industry Authority's Aquaculture Research Unit at Ardtoe, Scotland, with the Scottish Office Aberdeen Marine Laboratory and the Institute of Aquaculture at the University of Stirling providing additional specialized inputs.[53] Like the Austevoll station in Norway, the Ardtoe facility undertakes work on all phases of the halibut production cycle, including broodstock management, larval rearing and on- growing.

There are four commercial hatcheries in the UK which produced 25,000 juvenile halibut for sale in 1997. This increased to 140,000 in 1998 and this is expected to double to 280,000 in 1999.[54]

The Scots believe that since they are at the southern limit of the Atlantic halibut's natural range, they have especially favorable sea water temperatures for rapid growth (it rarely falls below 7°C) and this has encouraged several companies to begin pilot scale programs. There is nothing on the scale of Stolt Sea Farm's effort in Norway, but Marine Harvest McConnell (MHM), one of the world's leading salmon farming companies, test marketed 1,100 pounds of farmed halibut in 1997 and is optimistic about future prospects for halibut as an aquaculture species.[11] Total UK production in 1997 was 6,600 pounds.[55] MHM expects to put 50,000 - 100,000 juveniles into sea cages in 1998, which should yield between 300,000 -600,000 pounds in two or three years.[56]

Active in the overall development and promotion of halibut farming in Scotland is the British Halibut Association (BHA) which was formed in 1987. Included among its members are the four commercial hatcheries, several feed companies, salmon farmers who are interested to diversify and the Highlands and Islands Enterprise Board, which has been highly supportive of all aquaculture development in Scotland. The BHA recently announced a one year appointment of a 'strategy development consultant' to set future direction, find funds for R & D, ensure active political representation and set quality standards for the new industry "from egg to the plate". Though it is expected that only 11,000 pounds of farmed halibut will be produced by Scottish farmers in 1998, projections for 2011 are for 22 million pounds.[57]

2.3 Iceland

Halibut farming in Iceland is limited to the effort of one company, Fiskeldi Eyafjardar Ltd (Fiskey), which has been working on it in cooperation with Icelandic and international research institutes since 1987. The Company produced 50,000 juveniles in 1997 and had produced 150,000 by the end of May 1998. It expects to sell 22,000 lbs of farmed halibut in 1998, increasing to 110,000 lbs in 1999 and 220,000 lbs in 2000.[58]

Fiskey's halibut are grown in land based tanks rather than sea cages, which some believe are better suited for this species. During the late 1980's, several land based salmon farms were built in Iceland to take advantage of geothermally warmed sea water which is available in the southwest region near Reykjavik. Most of these farms proved to be unprofitable, but their conversion for halibut production may provide Iceland with an interesting opportunity. The ability to provide optimum water temperatures for different stages in the growth cycle is likely to be an especially significant advantage in halibut farming.

[53] Gillespie, M., 1996. UK halibut nearing quantity production. Fish Farmer, Vol. 19, No. 5, pp. 36-27.

[54] Jim Buchanan, British Halibut Association. Personal communication.

[55] Anon., 1997, British halibut production of 3 tonnes this year. Seafarm Business Review, 10.31.97.

[56] Anon., 1998. Halibut set to come on stream. Scottish Fish Farmer, No. 112, p. 9.

[57] Holmyard, N., 1998. Slaski champions halibut cause. Fish Farmer, Vol. 21, No. 4, p. 20.

[58] Anon., 1998. Juvenile halibut success in Iceland. Fish Farming International, May, p. 9.

3.4 Canada

Most of the halibut farming activity in Canada is on the east coast where government is working closely with private companies to develop this as a new aquaculture industry. The Department of Fisheries and Ocean's (DFO) Biological Station at St. Andrews, New Brunswick maintains a halibut broodstock and provides eggs to would be commercial producers. It also cooperates with an on-site industry partner (Maritime Mariculture) in a hatchery which produced more than 10,000 juveniles in 1997. The Canadian Center for Fisheries and Innovation (CCFI) and the Ocean Sciences Center (OSC) at Memorial University in Newfoundland targeted halibut aquaculture as a top priority for research in 1995 and recently announced over $CDN 1 million in funding for a new hatchery project. This includes a technology transfer agreement with Maritime Mariculture and its Norwegian collaborator, AMY A/S, which will provide OSC with full access to Norwegian halibut technology.[59] Most of the funding for this program is provided through the Canadian / Newfoundland Agreement on Economic Renewal which is investing a total of $CDN 20 million to assist the aquaculture industry in Newfoundland. The government of Nova Scotia also supports the development of aquaculture and in 1995 sent a fact finding mission to Europe to study developments there, especially work on halibut.[60]

There are several commercial initiatives in eastern Canada in addition to Maritime Mariculture, which has already been mentioned. One of these, in Nova Scotia, is reportedly cooperating with Icelandic company Fiskey, another is cooperating with Marine Harvest McConnell.[61] Between them they have access to much of the leading European technology and are expected to produce a combined total of about 40,000 juveniles in 1998.[62]

Given this level of interest, it is surprising that a recent technical paper, published by the Nova Scotia Department of Aquaculture and Fisheries, concludes that prospects for halibut aquaculture in the province may not be very good. The report notes that, halibut will not grow for extended periods during the winter because sea water temperatures in Nova Scotia fall below 4°C. Halibut do not grow at these low temperatures, which means that invested capital will be unproductive for several months.[63] The report emphasizes that if halibut farming is to be established in the province, its viability will depend on producers' ability to maintain high selling prices.

In the long term, the west coast of Canada (BC) may prove more amenable to halibut farming than the east coast, because sea water temperatures there are much less variable and may be close to ideal. This will require culture techniques to be adapted to Pacific halibut, on which there has been much less work, though the two species are very similar biologically and it is likely that this can be done. [64] Therefore it is also surprising that there is, presently, no government funding for Pacific halibut aquaculture in BC. Some broodstock are held at the DFO Biological Station, Nanaimo, as a hold over from an earlier program, but that is all. In the private sector, there is interest among Pacific halibut fishermen in the idea of 'storing' wild caught, market size halibut in net pens for sale in the winter.[65] This is not farming in the conventional sense, though, if the fish are fed, some weight gain may be achieved. It is an approach to marketing wild fish which is used successfully in other fisheries, notably for tuna in Mexico and Australia.

[59] CCFI web page.

[60] Helm, M., 1995. Marine Finfish Farming in northern Europe. A report of the Nova Scotia Department of Fisheries Fact Finding Mission to the United Kingdom, the Isle of Man and Norway. 55 pp.

[61] Andrew Storey, personal communication.

[62] Jonathon Moir, personal communication.

[63] Nova Scotia Department of Aquaculture and Fisheries, 1998. Nova Scotia Aquaculture: Comparative analysis of development issues and species economic potential.

[64] Stickney, R.R. and D. Seawright, 1993. A Bibliography on Atlantic Halibut (*Hippoglossus hippoglossus)* and Pacific Halibut (*Hippoglossus stenolepis)* Culture, with Abstracts. International Pacific Halibut Commission, Technical Report no. 30.

3.5 Ireland

Ireland is one of the few countries that have actually produced some farmed halibut for sale. These were produced in a land based system on Cape Clear, Eileabo Teo and were slaughtered prematurely when farmed turbot, at the same farm, became infected with a disease. Though the halibut were not affected, they were slaughtered as a precaution and 1500 fish, out of a total of 3000, were sold.[66] The farm has since been restocked with 1000 juveniles from the Ardtoe hatchery in Scotland, there being no government research on halibut in Ireland.[67]

3.6 Chile

The success of Chile's salmon farming industry has inspired a commitment to the development of aquaculture which makes the country one of the world's leading innovators in this industry. Fundacion Chile, which is a public/private technology transfer organization, has recently imported broodstock and juvenile Atlantic halibut from the Canadian Maritimes and Europe. This is part of its program to develop the farming of three non native flatfish species, the other two being hirame (*Paralychthys olivaceus*) and the European turbot (*Scopthalmus maximus*).[68] To date, no juvenile or market ready halibut have been produced, but excellent growing conditions and the demonstrated skill of its fish farmers make it probable that Chile will, eventually, become an important producer.

3.7 USA

Work on halibut farming in the U.S. has been confined to the west coast where, from 1988-1997 Pacific halibut broodstock were held at the U.S. Fish and Wildlife facility at Marrowstone Island, Washington. Research on spawning and early larval rearing was funded by the US Fish and Wildlife Service, the University of Washington and the International Pacific Halibut Commission.[69] No weaned juveniles were ever produced and the program has now been terminated.

4. STATUS, COSTS AND TECHNICAL HURDLES

4.1 Current status

Today, after over 10 years of intensive public and private sector research, halibut farming appears to be on the brink of large scale commercial development. Total world wide production of juveniles in 1998 will probably exceed one million, more than double the number for 1997. This will mean more commercial farmers will be able to obtain juveniles for on-growing trials, which, in turn, will spur the development of on-growing techniques.

Olsen (in press)[70] charted the number of juveniles produced by the leading halibut farming countries up to 1997 (See Figure 2, Page 15). This shows how dominant Norway is at present and the extent of the problems there in 1995 and 1996, which exposed the vulnerability of hatchery methods that relied on filtering sea water to obtain seasonally available copepods for larval food (Section 2.1.4.).

[65] Dale Blackburn, personal communication.

[66] Anon., 1998. Satisfactory results. Seafarm Business Review, 02.10.98.

[67] Anon., 1998. New halibut trial. Seafarm Business Review, 05.14.98.

[68] Fundacion Chile web site.

[69] Stickney, R.R.,1994. A review of the research efforts on Pacific halibut, *Hippoglossus stenolepis,* with emphasis on research and development needs. Marine Fish Culture and Enhancement, Seattle, WA. Washington Sea Grant, pp.39-41.

[70] Olsen,Y., 1988. Status of the Cultivation Technology for Production of Atlantic Halibut (*Hippoglossus hippoglossus*) juveniles in Norway / Europe. Aquaculture, in press.

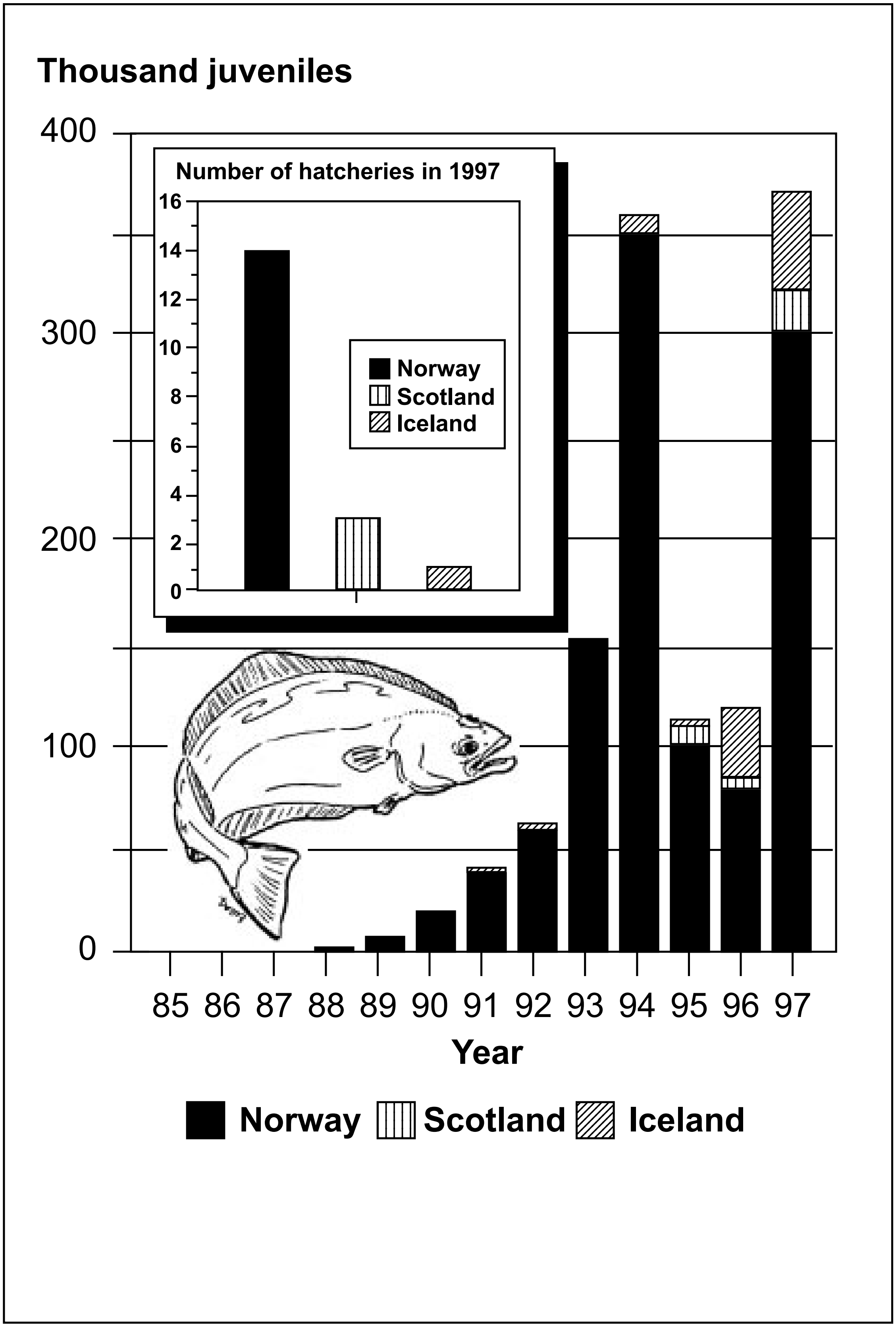

Figure 2. Production of halibut juveniles from 1987-1997 in Norway, Scotland and Iceland. Reproduced from Olsen, 1998

It is possible to estimate the amount of farmed halibut likely to be sold in the next four years, based on the number of juveniles produced in prior years. Table 4 provides such an estimate, assuming that juveniles produced between 1995 - 1998 will be grown to an average market weight of 10 pounds with survival of 80% (Sections 2.3.3. and 2.3.4.) and are sold between 1998 - 2001. Of course, the amount actually produced could be more or less than this, if mishaps result in lower survival, or if growers delay harvesting in order to grow bigger fish, as Stolt Sea Farm is apparently doing (Section 3.1). Whatever happens in practice, however, the volumes of farmed halibut produced in the next three or four years will be quite small. What happens after this depends on the number of juveniles produced in future, and this seems likely to increase quite quickly. The critical element then will be the cost of on-growing them to market size.

Table 4. Amount of farmed halibut likely to be produced up to 2001.

Juvenile year class	No. of juveniles	Year harvested	Pounds produced
1995	120,000	1998	960,000
1996	130,000	1999	1,040,000
1997	340,000	2000	2,960,000
1998	780,000*	2001	6,240,000

*This is based on estimates of 400,000 from Norway, 140,000 from UK, 200,000 from Iceland and 40,000 from Canada (see Section 3). Of these, the only officially confirmed number is from the UK .

4.2 Total Costs of Production

The cost of farming halibut, at this early stage in the development of the technology, is likely to be high, investment in it being justified on the grounds that initial prices will also be high and that costs will come down as the technology is refined. Because there has been so little farmed halibut produced commercially, current information on costs is mostly in the form of projections, rather than costs actually achieved in practice. Table 5 gives projections from three sources and compares them with the author's estimate of a current, composite cost for growing Atlantic salmon.[71] All costs are in US dollars and are expressed as components of the total cost to grow one pound of finished fish, i.e., an ungutted, ex-farm cost, before processing, packaging and selling expenses.

Summarizing the projections in this way required some approximations. For example, Englesen's 1995 costs were expressed in Norwegian Kroner and have been converted to US dollars at a rate of NOK 7 per USD. Similarly, the 1998 costs from Nova Scotia are presented in Canadian dollars, which have been converted at a rate of USD0.65 per $CDN. Another approximation was made for depreciation in the Nova Scotia costs, because no figure is given for depreciation in this reference. It is estimated in Table 5, assuming a 15 year average life of the fixed assets, for which a cost is given. Finally, the cited references do not make clear what costs are allocated to 'Operations' versus 'Administration', so differences shown between these categories may not be very meaningful.

[71] It should be noted that many salmon farmers, particularly in Norway and Chile produce below this cost. A recent Norwegian report calculated average pre-slaughter costs in Norway in 1997 at $1.01/lb

Table 5. Cost estimates for the production of farmed halibut in USD/lb, live weight of fish produced.

	Sutherland '92[72]	Engelsen '95[73]	Nova Scotia '98[74]	Atl. Salmon '98
Cost category	Net pen farm, 220,000 lbs/yr	On-shore farm, 2 million lbs/yr	On-shore farm* 600,000 lbs/yr	Composite cost
Juveniles	0.50	0.30	0.28	0.17
Feed	0.56	0.40	0.42	0.53
Labor	0.34	0.46	0.25	0.15
Operations**	0.36	0.32	0.60	0.14
Admin	0.11	0.15	0.03	0.12
Depreciation	0.34	0.22	0.28	0.08
TOTAL	2.21	1.85	1.86	1.19

* This is a proposed recirculation facility, rather than a simple 'flow through' farm.
** Includes livestock mortality insurance

The estimates show that the cost to grow halibut, based on current technology, is likely to be between $1.85 - $2.21/lb. Whether or not the first commercial farms will be able to produce at these costs remains to be seen. It is likely, in practice, that the actual range of costs will be wider than this, with smaller farms producing at a cost higher than $2.21/lb. In the context of the present study, however, this is not as important as trying to understand what will happen to these costs in the longer term, say 15 to 20 years. For this, it is necessary to examine the individual components of cost in Table 5 in some detail, and what follows is an attempt to do this, drawing on experience from the farmed salmon industry where appropriate.

4.2.1 Juvenile costs

In 1992, Sutherland made an early attempt to estimate the cost of producing halibut juveniles in a hypothetical hatchery which would produce 108,000 x 40 gram juveniles per year (Table 6) and concluded they would cost $4.66 each.[75] In 1995 Olsen reported that it cost $6.60 each to produce 5 gram juveniles in Norway, using semi-extensive hatchery methods.[76] In 1998, the selling price for a 5 gram juvenile in Norway was about $10.00 (70 NOK)[77], at which price at least one commercial Norwegian halibut hatchery claims to have been profitable in 1997.[78]

It is inevitable that the cost to produce halibut juveniles will come down in future as larval survival is improved and the scale of production is increased. Sutherland estimated that, if survival in his relatively small, hypothetical hatchery could be increased from 3.1% to 20%, the cost per juvenile would reduce from $4.66 to $3.34. For a larger hatchery producing, say one million juveniles per year, it is quite possible that the cost could be 30% lower than this, bringing it down to $2.35 each. By comparison, the current cost of producing a salmon smolt is about $0.75 - $1.25.

[72] Sutherland, R., 1997. Review of the economics of potential systems for farmed production of Atlantic halibut. Aquaculture Europe (magazine of the European Aquaculture Society), Vol. 21, No. 4, pp.6-11. (cites his own 1992 projection)

[73] Englesen, R., 1995. Economical view on halibut on-growing (in Norwegian). In Kveite - fra forsning til naering (*Halibut - from R&D to industry)*. Pitman, K., A.G. Kjorrefjord, L. Berg and R.Englesen, eds), Stiftelsen Havbrukskunnskap, Bergen, pp. 179-198.

[74] Nova Scotia Department of Aquaculture and Fisheries, 1998. Nova Scotia Aquaculture: Comparative analysis of development issues and species economic potential.

[75] Sutherland, R. 1992a. The economics of halibut production and estimation of feasible prices for the purchase of juvenile fish. Report for the British Halibut Association. SAC Aberdeen. Cited in: Sutherland, R., 1997. Review of the economics of potential systems for farmed production of Atlantic halibut. Aquaculture Europe (magazine of the European Aquaculture Society), Vol. 21, No. 4, pp.6-11.

[76] Olsen, 1995. Unpublished. Cited in: Sutherland, R., 1997. Review of the economics of potential systems for farmed production of Atlantic halibut. Aquaculture Europe (magazine of the European Aquaculture Society), Vol. 21, No. 4, pp.6-11.

[77] Anon., 1997. Halibut hatchlings: 70 Norwegian kroner per piece. Seafarm business review, 12.19.97.

[78] Anon., 1997. Now profiting on halibut. Seafarm business review, 08.27.97

Table 6 Estimated costs for a hatchery producing 108,000 juvenile halibut per annum of 40 grams each - adapted from Sutherland (1992a)

Cost Category	USD per annum*
Broodstock replacement	660
Feed	24,400
Transport and Marketing	24,750
Chemicals and consumables	33,000
Labor and management	173,000
Fuel and electricity	66,000
Repairs	27,440
Insurance	24,750
General overheads	21,450
Depreciation	107,300
TOTAL COSTS	502,750
Cost per juvenile produced	$4.66

* Converted from GB pounds at a rate of USD1.65:1GBP

It seems unlikely that juvenile halibut will ever be able to be produced as cheaply as salmon smolts. The hatchery process is clearly more complex than for salmon and production of live food is expensive. The present dependence on *Artemia,* as a live food, is a particular vulnerability because *Artemia* eggs are in short supply. A development priority for halibut hatcheries is to find ways to reduce this dependence. All this suggests, based on today's prices, that a range of between $2.00 - $2.50 each is a reasonable expectation for the cost of halibut juveniles 15 to 20 years from now.

However, the individual cost of juveniles is only one factor in determining their cost contribution to the finished weight of a farmed halibut. Grow-out survival and final harvest weight are equally important. Survival assumptions for the projections in Table 5 average about 86%, which does not leave much scope for improvement. Possibly, 90% survival may be achieved in years to come, which would save 5% on the cost of juveniles, but to plan on achieving better than this allows little margin for error. The average harvest weight of about 12 lbs, assumed by the authors cited in Table 5, similarly leaves limited opportunity for improvement, especially if males have to be harvested at 5-6 lbs before they mature. An important development goal for hatcheries is to learn how to produce all female, or sterile fish and it is expected that this will prove possible in a 15-20 year time scale. This would allow average harvest weights to be increased up to, perhaps, 15-20 pounds and would reduce the cost of juveniles shown in Table 5. by about 30%.

Taking these cost savings together, it is possible to see how juvenile costs could fall, eventually, to about $0.14/lb of finished weight produced, i.e., $2.25 per juvenile, divided by 90% survival, divided by 17.5 pounds average harvest weight. This would be comparable to salmon, even though halibut juveniles would cost twice as much as salmon smolts, and is made possible because of the 17.5 pound harvest weight assumption, compared to about 10 pounds for salmon today. Of course salmon farmers could increase their harvest weights in years to come which would change this calculation, but, for now, this is a reasonable comparison.

4.2.2 Feed

Feed is a major cost in fish farming. In farmed salmon, for example, it is almost half the total cost (Table 5). The key factors governing feed cost are the feed price and food conversion ratio (FCR). Fish, such as salmon and halibut, require high quality protein in their feed at levels between 40%-50%. Today, this mostly comes from fish meal, which is expensive and the main determinant of feed price.[79] In salmon, it is now possible to replace some of the fish meal with other ingredients, such as soy and canola protein, and recent trials have shown that this is also possible for halibut, providing the feed is flavored with an attractant - in this case squid meal in an oil emulsion. [80] Other important ingredients in fish feed are fish oil and, in the case of salmon, carotenoid pigments to provide red meat color. The FCR determines how much feed is needed to achieve the required weight gain. For salmon, the FCR is usually between 1.1 to 1.4:1, with more and more farmers achieving values at the lower end of this range.

Understanding of the nutritional needs of halibut is still rudimentary. Until quite recently, farmed halibut were mostly fed on wet, or moist feeds consisting of minced, or cut up raw fish, or minced fish mixed with a dry meal binder to make sausage like feed pellets. Such feeds are usually more palatable to fish than dry feeds and have often been used in the early stages of farming of a new species. Both Sutherland's and Englesen's estimated costs in Table 5 are based on the use of moist feeds, whereas the Nova Scotia projections assume that dry feeds are used. Dry feeds for marine fish have become more available in the last few years because of experience gained in feeding fish, such as sea bass and sea bream. That there are not greater differences between the different projections is because the fish protein, on which all the feeds are based, has about the same market value, whether it is wet or dry.

Because of their convenience and consistency, dry feeds will inevitably be used more and more as halibut farming develops. The Nova Scotia feed cost in Table 5 assumes a feed price of $0.47/lb and a FCR of 0.9:1.[81] By comparison, the feed cost for salmon assumes a price of $0.44/lb and a FCR of 1.2:1. As noted in Section 2.3.2, halibut are very efficient converters of feed and FCR's below 1:1 have been achieved routinely on an experimental scale. To achieve such levels under commercial conditions is another matter and the assumption in the Nova Scotia study may be over optimistic. On the other hand, the future price of halibut feed is likely to be about $0.38/lb, not $0.47/lb, which this study assumes. This is because it will be made from roughly the same ingredients as salmon feeds, but without carotenoid pigments, a cost saving of 12-15% (see Section 2.3.2.). At a price of $0.38/lb and a more conservative FCR of 1.1:1, a re-calculated feed cost for halibut would be $0.42/lb, coincidentally the same as the Nova Scotia projections, but estimated using different assumptions. Though the present price of halibut feed is certainly more than $0.38/lb, due to limited demand and a cautious approach to formulation, it will almost certainly come down in future. When it does, halibut will then be significantly less expensive to feed than salmon.

An important qualification to this analysis concerns FCR's for halibut grown in net pens. Since they are primarily bottom dwellers and feeders, it is difficult to feed them in net pens without some feed wastage. The Nova Scotia projections (Table 5) assume a FCR of 1.5:1 for a net pen farm, versus 0.9:1 for an on-shore facility, suggesting a great deal of wastage. This is a huge difference and if the gap cannot

[79] During 1998 fish meal has been particularly expensive because of reduced landings in the industrial fisheries of Chile and Peru, caused by El Nino. Prices are now starting to come down and it is likely that they will eventually return to a 'normal' level which is, typically, about twice the price of soy bean meal, a differential which reflects the relative quantity and quality of protein in these meals.

[80] Berge, G. M., Grisdale-Helland, B., Helland, S.J., Sveier, H and K. Bekkevold, 1997. Soy protein concentrate in diets for Atlantic halibut. Aquaculture Trondheim '97, European Aquaculture Society, Abstracts pp. 34.

[81] It is possible to achieve FCR's of less than 1:1 because the conversion is of dry weight feed to wet weight of fish.

be narrowed, it argues strongly for on-shore systems as a future, preferred method of halibut farming. It seems likely, however, that the feed wastage problem can be overcome , or at least greatly reduced, and that production in net pens will, ultimately, prove to be the lowest cost method of halibut farming.

4.2.3 Labor

Many factors will affect labor requirements at this early stage in the development of halibut farming. It is probable that most commercial producers are still very inefficient as they learn how to work with this new species, and rank labor efficiency below biological performance as an immediate priority. The average productivity assumed by the authors cited in Table 5 is 77,000 lbs per man year. By comparison, salmon farms routinely exceed 200,000 lbs per man year, with farms in Norway reported to have averaged 425,000 lbs in 1997.[82] Bearing in mind that the costs in Table 5 are only projections and still have to be achieved in practice, it seems likely to be a long time, if ever, before halibut farms can approach productivity achieved in the salmon industry. For the purposes of this analysis, a productivity level of 150,000 lbs per man year is considered a realistic target 15 to 20 years from now. Depending on wage rates, this would give the labor cost of between $0.016 - $0.22/lb live weight of halibut produced.

4.2.4 Operations costs

These are all the costs associated with the logistic support and maintenance of a farm, such as electricity, fuel, repairs, medications and insurance, and can vary considerably depending on the farming system. For example, an on-shore farm will incur the cost of pumping water, while a net pen farm bears all the costs associated with running work boats. Typically, an on-shore farm will have higher overall operations costs than a net pen facility, but would expect to recover such costs through better fish performance; though this expectation has not been realized in the farming of salmon, which is why so many on-shore salmon farms have failed. Presently, however, there is not enough commercial experience of growing halibut in either system to know and further speculation on what the differences may be seems pointless. What can be noted is that operations costs in salmon farming are now down to about $0.14/lb, which provides halibut farmers with a benchmark, even if they cannot reach it.

4.2.5 Administration

Administration costs are sensitive to the scale of operation. It is, therefore, surprising that the costs in Table 5 are as low as they are. In part, this may be because they are classified differently by different authors, but there is little merit in speculating further. All that can be said now is that small, independent halibut farms will have higher costs of administration than most salmon farms, but where halibut production is integrated into larger aquacultural businesses, the costs are likely to be about the same.

4.2.6 Depreciation

Facilities required to farm halibut will be more costly than those used for salmon, because halibut grow more slowly and need more space on which to spread

[82] Anon., 1998. Spotlight on growth, costs and efficiency. Fish Farmer, Nov/Dec. p34.

themselves. Slower growth means more living inventory must be held in a halibut farm than in a salmon farm in order to produce the same amount of fish. A rough estimate would be 1.7 times more, based on growth times to market size of 30 to 36 and 18 to 21 months respectively. More space is needed because halibut spend most of their time on, or near, the bottom and not dispersed in the water column (see Section 2.3.1). For example, 220,000 lbs of halibut at a density of 11lbs per square foot (see Table 1), require 20,000 square feet of bottom surface on which to space themselves. By comparison, the same amount of salmon in a net pen 30' deep, at a typical density of 1lb per cubic foot, need only 7,350 square feet. One of the ways in which salmon net pen costs have been reduced is by increasing depth, which simply requires the addition of some netting to increase rearing volume. To achieve a comparable increase in a flatfish cage, it is necessary to expand the size of the structure which supports the net, and this is more expensive. The same principle applies to the design and cost of on-shore systems.

The high capital cost of rearing facilities is a significant problem for the new industry. Some ways in which costs might be reduced are:

- grow fish faster,
- grow fish at higher stocking densities,
- use 'shelves' in tanks or net pens for halibut to rest on, thus making better use of cubic capacity,
- design special flatfish cages which maximize floor area while minimizing expensive surface superstructure,
- use very shallow raceways in on-shore systems (see Section 2.2).

Pending advances in any or all of these areas, the capital cost of a halibut farm will remain much higher than it is for a salmon farm. The Nova Scotia Study[83], based on Norwegian data, projects an investment of $4.16/lb of capacity for an on-shore, recirculation system and $2.54/lb for a net pen farm, each of them producing 600,000 pounds per year.

Depreciation of such expensive assets is a major cost of production. If the expected, average, useful life is 15 years for the on-shore facility and 7 years for net pens, depreciation would be $0.28/lb and $0.36/lb respectively, compared to a cost for salmon of only $0.08/lb (Table 5). Like other costs in halibut farming, these costs will come down as competition inspires innovation, but it is hard to see how they will ever be as low as they are for salmon because of halibut's needs for space. This is an intrinsic disadvantage of flatfish for aquaculture and an important challenge for designers of flatfish farming systems.

4.2.7 Cost of Capital

Capital is required in halibut farming for plant and equipment (fixed assets) and for an inventory of living fish (working capital). Both needs are substantial for reasons explained above. Depending on how the business is financed, there is either an actual cost of interest for this capital, if the money is borrowed, or an opportunity cost, i.e., interest which the money could have earned elsewhere, if it is provided as equity. Financial analyses of fish farms usually show the effect of these costs by calculating a return on investment, or an internal rate of return. To do this, however, it is necessary

[83] Nova Scotia Department of Aquaculture and Fisheries, 1998. Nova Scotia Aquaculture: Comparative analysis of development issues and species economic potential.

to assume a selling price which, at this stage in the development of halibut farming, is even more unpredictable than the production costs. For this reason, it is suggested that it is more meaningful, for the present purpose, simply to show capital investment as a cost of production, at an assumed rate of interest. This highlights the consequences of capital needs and sets a price at which fish must be sold in order to return the assumed rate of interest to investors.

If an interest rate of 10% is assumed, the cost of capital is 10% of the fixed capital investment per pound estimated in Section 4.2.6. , i.e., $0.42/lb for an on-shore farm and $0.25/lb for net pens. To this must be added the cost of working capital invested in the build up of three year classes of live inventory before first sales are made.[84] Based on Norwegian data, the Nova Scotia study (Table 5) calculated inventory of 680,000 lbs for 600,000 lbs of annual production from an on-shore recirculation system, and 800,000 lbs for an equivalent sized net pen farm. The difference is due to the faster growth assumed in the on-shore system, where growing temperatures are maintained in an optimal range throughout the year. Most of the weight and cost of this inventory will be made up of near market sized fish in which about $2.00 /lb will have been invested. A lesser proportion will be smaller fish which, on a per unit weight basis, will have cost more, because of a disproportionate effect of the cost of juveniles . On average, total investment in inventory might be about $2.50/lb, which would set the working capital needs at $1.7million for the on-shore farm and $2.0 million for the net-pen farm. At 10% interest, this would add $0.28/lb and $0.33/lb, respectively, to production costs.

This analysis is admittedly rough, but there is little point in complicating it now when there is considerable margin for error in all the assumptions made. What it shows, however, is that the cost of capital is substantial. When interest on working capital is added to interest on fixed capital, the total cost, based on present facility designs and expected growth rates, is $0.70/lb and $0.58/lb for an on-shore farm and a net-pen farm respectively. This is much more than it is for salmon, for which an equivalent cost, today, is about $0.15/lb. It emphasizes, once again, the pressure halibut farmers will feel to find ways to accelerate halibut growth and simplify the design of farming installations.

When the cost of capital is added to the projected costs of production in Table 5, the total range of estimated production cost increases from $1.85 - $2.21/lb to $2.43 - $2.79/lb, this now being the price range at which farmed halibut would have to be sold if a farm is to break even, after paying 10% interest on all the capital employed. Another way to look at it is that this is the selling price range at which a farm would earn 10% return on capital employed, if all the capital was invested as equity. And, since 10% is not enough to justify the risk in a new business like halibut farming, an investor would, presumably, expect to receive prices substantially higher than this.

4.3 Future production costs

Though the foregoing analysis is somewhat labored, its purpose is to provide a basis for speculation on the possible costs of halibut farming **15 to 20 years** from now. By this time, **production of farmed halibut could easily be equal to, or more, than landings of wild halibut of both the Pacific and Atlantic species**. The competitiveness of such a supply will depend on its cost, and the figures in Table 7 are

[84] Once sales begin a fish farm can be thought of as having reached a ‘steady state’, i.e. there is an inventory, or biomass of fish, whose annual weight gain equals the annual weight of fish sold . Within a year, sales and weight gain may not always be perfectly aligned but, year on year they balance, providing the farm is neither expanding nor contracting its output. The average biomass during the year represents the average investment in inventory and defines the requirement for working capital.

an attempt to project what this may be, based on today's prices for key inputs and assuming technical advances contemplated in the discussion above.

A key question is the size at which fish will be harvested. This will depend on the future cost of juveniles, the rate at which they can be grown, the market acceptance for fish of different sizes and the price at which they can be sold. There are potential cost advantages in producing smaller fish, if the cost of juveniles is low enough. This is because the live fish inventory can be turned over faster, reducing the need to hold such a large biomass and, in turn, the size of the facility required to hold it. Since depreciation and the cost of capital are such important items of cost, this could result in substantial savings. However, if juveniles remain expensive, this is unlikely to offer any advantage. The estimates in Table 7 assume the production of larger fish, since there is no basis for assuming that the cost of juveniles will fall below \$2.00 - \$2.50 each. Moreover, for the purpose of this study, larger fish are more likely to compete directly with wild halibut.

Table 7 Production cost estimates for farmed halibut in 15 to 20 years, based on the 1998 price of key inputs.

Cost category	Assumption	Cost range, \$/lb High	Cost range, \$/lb Low
Juveniles	Juveniles will cost \$2.00 - \$2.50 each and will be grown to a weight of 15 - 20 pounds with 90% survival (Section 4.2.1)	0.19	0.11
Feed	Feed price will fall to \$0.38/lb. FCR will be 0.9:1 to 1.1:1 (Section 4.2.2)	0.42	0.34
Labor	Productivity will reach 150,000 lbs per man year. Average wages \$2000 - \$2750 per month (Section 4.2.3)	0.22	0.16
Operations	Costs will be 10 - 30% higher than the current costs in salmon farming	0.18	0.15
Administration	Halibut farms will be integrated into larger aquaculture businesses with the same administration costs as for salmon today	0.12	0.12
Depreciation	Net pens will become the lowest cost method of farming. Better designs and larger farms will lead to a 30 - 60% reduction in the cost of fixed assets. (Section 4.2.6).	0.25	0.14
TOTAL COST	Before the cost of capital	1.38	1.02
Cost of capital at 10%	Fixed capital investment will reduce by 30 - 60% for reasons stated in 'Depreciation' above. There will be no reduction in working capital because advances in growth rate will be offset by growing the fish to a larger size	0.51	0.43
TOTAL COST	After financing	1.89	1.45

It must be emphasized that these cost projections are highly speculative. There are all kinds of things which could occur in 15 to 20 years to change the assumptions. For example, new feeds could be formulated based on lower cost ingredients, or large scale holding structures on the sea bed could be developed, which could reduce the investment needed in rearing space and be better suited to the needs of a flatfish like halibut. Alternatively, new problems could arise, such as the expression of hitherto unrecognized diseases, which would set the industry back and increase costs until the problem was resolved. **Nonetheless, for the purpose of looking ahead and trying to understand what may be possible, the projections in Table 7 show that costs in future could be about 30 - 40% lower than they are projected to be today, if certain technical hurdles are overcome.** Based on experience in salmon farming, this is reasonable and suggests that, 15 to 20 years from now, halibut farmers will need a price of between $1.45 - $1.89/lb, live weight, in order to make a return on capital employed of 10%.

5. MARKETS AND MARKETING

5.1 Short Term Outlook

As noted previously, the short term outlook for the production of farmed halibut can be estimated from a knowledge of the annual number of juvenile halibut produced in the world's hatcheries. Production of 780,000 juveniles in 1998 (Table 4) could yield over **six million pounds of farmed halibut between 2001 and 2003**, depending on the size and age at which they are harvested. Nearly all of this will be produced in N. Europe and the volume is close to the present wild catch of Atlantic halibut which, in 1995 was 8.1 million pounds, having declined from 17.7 million pounds in 1986 (Table8)[85]. By 2003, juveniles produced in 1999 and 2000 will also contribute to the farmed total. Numbers of these can only be guessed at presently, but an increase over 1998 is almost inevitable. **So, five years from now, though landings of wild Pacific halibut are still likely to dominate the total world supply (Table 8), production of farmed Atlantic halibut could easily equal, or exceed, landings of wild Atlantic halibut.**

Table 8. Wild Halibut Landings (millions of lbs), 1986 and 1995.

Atlantic halibut	1986	1995
Canada	8.14	1.91
Iceland	3.56	1.95
Faroe Islands	1.41	1.44
Norway	1.73	1.21
All other (28)	2.84	1.59
TOTAL Atlantic halibut	17.08	8.10
TOTAL Pacific halibut (landings + imports)[86]	87,589	58,060

In many ways the situation is analogous to Atlantic salmon farming in the late 70's and early 80's. The wild harvest of Atlantic salmon at that time was only about 20 million pounds and was soon exceeded by the supply of farmed salmon, as this new aquaculture industry developed. This might have been expected to lead to an immediate price collapse, but this did not happen for several years, by which time

[85] FAO, 1995. Yearbook of Fishery Statistics. Vol. 80. Cited in: Nova Scotia Department of Aquaculture and Fisheries, 1998. Nova Scotia Aquaculture: Comparative analysis of development issues and species economic potential.

[86] Johnson, H.M. and I. Dore, 1994 and 1997. United States Seafood Industry. H.M. Johnson Associates, Bellevue, WA.

annual production of farmed salmon was more than 200 million pounds. There was, in fact, a latent unrecognized demand for fresh salmon, much larger than would have been predicted, based on then current consumption of wild Atlantic salmon. The new farmed product filled a market void and farmers were able to keep increasing their production for several years before any sign of market weakness became apparent.

A presumption in the development of halibut farming is that a similar situation applies. A major market evaluation conducted for multiple Norwegian clients in 1992[87] notes: *"Fresh salmon expanded all major European markets considerably in the early eighties. There are good reasons to believe the same will happen with halibut".* How far this analogy extends is open to question, but in the next five years, at least, it does not seem likely that supplies of farmed halibut will unsettle markets for wild halibut of either Atlantic or Pacific origin. During this period, halibut farmers will focus their marketing effort on upscale restaurants and retail outlets, mostly in N. Europe, where halibut is highly regarded. They will promote it as Atlantic halibut and will emphasize its consistent quality, size and year round availability, though they are likely to get their best prices during late fall, winter and spring, when wild Atlantic halibut are most scarce. Their promotional efforts may, actually, increase, or re-awaken, interest in fresh halibut as a category, much as promotion by salmon farmers stimulated new demand for fresh salmon in the early 80's. In turn, this could open up new opportunities for fresh Pacific halibut, now that it is available for a substantial part of the year.

5.2 Quality considerations

If Pacific halibut marketers are to take advantage of possible renewed European interest in halibut, it is suggested that a key to doing so is quality. Initially, this means the development of a detailed understanding of the differences, if any, between Atlantic and Pacific halibut and, subsequently between wild and farmed fish. **Halibut farmers are already going to considerable lengths to understand the quality attributes of their product and it might be beneficial for Pacific halibut producers to do the same.** Merely promoting it as 'wild caught from Alaska' is helpful, but not enough. Wholesale buyers will want to know about the actual benefits of the fish they buy as well as those that their customers may perceive.

Hard data on the actual differences between the two species is limited and references in the literature to perceived differences are contradictory. The Norwegian market evaluation[88], referred to above, notes: *"The perceived similarity between the two probably differs from segment to segment. It is likely that up market segments, such as some hotels and restaurants are less willing than other segments to substitute Atlantic for Pacific. Although no attempts have been made to estimate cross-price elasticities, statements from industry participants indicate that the impact of Pacific halibut supply on European prices and demand for Atlantic halibut is greater than its market share in Europe would suggest. This is probably due to the fact that several market segments view the two as close substitutes and use Pacific halibut price offers as reference points in negotiations with Atlantic halibut suppliers."*

In eastern U.S. markets, where Atlantic and Pacific halibut are sometimes both available fresh at the same time, Atlantic halibut usually commands a $0.25 - $0.50/lb premium over Pacific halibut,[89] suggesting a mild preference for the former. On the

[87] NHH and PA Consulting, 1992. Market Evaluation of Farmed Halibut. A NTNF, Stolt Sea Farm A/S and T. Skretting A/S/BP Nutrition Aquaculture Project.

[88] NHH and PA Consulting, 1992. Market Evaluation of Farmed Halibut. A NTNF, Stolt Sea Farm A/S and T. Skretting A/S/BP Nutrition Aquaculture Project.

[89] Seafood Price Current. Urner Barry.

other hand, a review of the present and future markets for farmed Atlantic halibut conducted by the UK Seafish Industry Authority[90], which is pioneering the development of halibut farming in Scotland, notes: *"For the most part, Atlantic and Pacific halibut are interchangeable.."*

So, the differences may not be that great, but it is certain that Atlantic halibut farmers will try and make the most of such differences. It is suggested that a well documented comparison between Atlantic and Pacific halibut would help exporters of Pacific halibut take advantage of any new enthusiasm for halibut in Europe. Biologically, the two species are very close. In fact, they were both classified as subspecies of the species *Hippoglossus hippoglossus* until quite recently, when biologists changed their minds and determined that they were sufficiently different to be speciated separately. But a common name and biological similarity will not change perceptions. If it is perceived, or if it becomes perceived, that Atlantic halibut is the better of the two, it will be important to know why, so that something can be done about it. Hence, the recommendation for a well-documented comparison.

The only quality comparison between the two species of which this author is aware is an evaluation conducted by NMFS Utilization Research Division in 1984. One Atlantic halibut was compared with one Pacific halibut for flavor, texture, pH and color. Both fish were frozen soon after capture and stored for only a few weeks. Measured differences between the two were insignificant and it was concluded that the sensory properties of Pacific and Atlantic halibut are, therefore, the same.[91] A sampling of just two fish, however, is probably not enough to justify such a broad conclusion and further comparisons seem warranted.

In starting to document the quality attributes of their fish, the primary concerns of halibut farmers are to:

- Understand and demonstrate the benefits of small halibut in different, narrow size ranges and then to make a virtue of being able to supply these sizes consistently.
- Document the edible meat yield from fish of different sizes.
- Control the consistency of the sensory properties, such as fat content, and to learn how these might be altered by feeding different feeds.
- Insure that skin color is comparable to wild fish and, when it is not, to minimize negative perceptions.[92]

An example of the sort of work being done is provided by Nortvedt and Tuene.[93] They cut nine sections from fillets of farmed halibut which had been fed on different feeds and analyzed these for fat and protein content. They found that the fat content in the fillet increased from tail to head and that fish fed a 20-39% fat diet gave a fresher, more acidic flavor and more juicy consistency than fish fed 10% fat. They also documented detailed information on fillet yield.

This is the kind of detail which will be extremely useful in marketing programs for farmed halibut and would be no less useful to marketers of wild caught halibut. An obvious point of differentiation between farmed Atlantic halibut and wild Pacific halibut is fish size. Most wild fish will be substantially larger than the farmed product. It would be helpful to develop a clear understanding of how processors, wholesalers and consumers perceive the advantages and disadvantages of halibut of different size

[90] Gillespie, M., D Cleghorn and J. Moore, 1996. Review of present and Future Markets for Farmed Atlantic Halibut. EU Concerted Action Project No: AIR3-CT94-2094, Document No 8.

[91] Rick Ranter, NMFS. Personal communication.

[92] Pigment abnormalities have been a problem in the farming of several flatfish species and are thought to be caused by inadequate nutrition in the early larval stages. The white side of farmed flatfish can also be something less than pure white creating potential for negative perceptions.

[93] Nortvedt, R. and S. Tuene, 1996. Body composition and sensory assessment of three weight groups of Atlantic halibut (*Hippoglossus hippoglossus)* fed three pellet sizes and three dietary fat levels. Aquaculture: Special issue from VII International Symposium on Nutrition and Feeding of Fish, Texas, August 11 -15,1996.

and why. There are a number of other factors which may also have a bearing on quality, such as the time of year when fish are caught, the interval between capture and consumption and the part of the fish from which portions are cut. All of these variables may affect how the fish actually tastes when it comes to the final point of consumption. It is suggested that **definition of such measurable quality attributes will help marketers of wild Pacific halibut to compete with farmed fish and will serve to reinforce softer selling points such as those related to origin.**

5.3 Long Term Outlook

Those presently involved in halibut farming do not believe it will be ‘another salmon’. According to Marine Harvest McConnell, Scotland’s leading halibut producer “tonnages [of farmed halibut] produced will be much lower and it will be more akin to other high value species such as turbot”.[94] It is noteworthy, however, that the early salmon farmers felt that way about their industry too. Both participants in and observers of this new industry consistently failed to see how new technology would reduce costs, or to appreciate the fundamental advantages of salmon as an aquaculture species.

As noted in Section 1, halibut has some of these same advantages. It has several characteristics which make it an efficient farm fish and others which make it highly desirable from a consumers point of view. These include, pure white meat, good texture, mild taste, no pin bones, good shelf life and the fact that it freezes well. These attributes give it mass market potential. If farming costs can be reduced, as they have been with salmon and as suggested in Table 7, demand could develop to become many times greater than it is today. This is a powerful incentive for today’s pioneer halibut farmers and the history of salmon farming suggests they will respond to it.

On the other hand, halibut has to compete in a seafood category which has many more direct competitors that does farmed salmon. As a white fish, it is almost universally acceptable, but there are numerous other high quality white fish out there which have similar appeal. In addition to wild halibut of both species, there are other wild caught fish such as cod, haddock, various other flatfish, Chilean sea bass and orange roughy. There are also white farmed fish such as catfish, hybrid striped bass, tilapia and the European sea bass and sea bream. Together these fish provide a spectrum of price, quality and perceived value within which wild halibut must find its niche. Since many of these fish are already available year round, this easy point of differentiation from which farmed salmon benefited so much, will be less of an advantage.

A key in what eventually happens will be the cost of farmed halibut meat as a raw material for further processed products and a key to this is fillet yield. It has already been emphasized (Section 2.3.5) that compared to its aquaculture competitors, the 60% yield of farmed halibut is high. In fact, halibut and salmon are some of the highest yielding of all fish, putting them at a significant advantage against other aquaculture species, especially as they move from their initial market status as ‘boutique’ items to become mainstream seafood offerings.

A good example of this can be seen in Europe presently, where sea bass and sea bream farmers are trying to expand demand by producing time-saving convenience products from their fish, but are finding that production of fillets is marginal due to the

[94] MacPhail, N. 1997. Another fishy tail from down on the farm. The Scotsman, 10.21.97.

poor yield.[95] This yield penalty is such that if sea bass and sea bream should ever have to compete, on price, with farmed halibut in the fillet market, farming costs for them would have to lower by one third or more. This is a huge difference and it is very unlikely to be possible, given that the main inputs of feed, labor and other operating costs are mostly the same.

For this reason, **of all the white fleshed aquaculture candidates, halibut stands out as having some of the best potential for the production of mass market, further processed products.** At 60% yield and assuming an ex-farm cost, before interest on capital, of $1.20/lb (the average of the high and low estimate in Table 7), the future cost of skinless, boneless halibut fillets would be $2.00/lb, almost exactly the same as farmed Atlantic salmon today at $1.98/lb, which suggests that halibut could, indeed, become another salmon. Difficulties must be overcome in both the hatchery and on-growing phases before this can happen, and it is by no means certain that solutions to them will be found . But there is clearly incentive to find them and, given the pace and breadth of aquaculture development, world wide, it seems likely these problems will be overcome.

6. CONCLUSIONS

The development of a new species for aquaculture always seems to take longer and cost more than any of its proponents expect. Halibut is no exception. The first experiments with it started in 1974 and intensive public and private sector research has been in process since 1988. Despite this effort the volume of farmed halibut which has actually been sold up to now is only a few hundred thousand pounds, and projections for the next three or four years suggest that sales volumes will continue to be fairly modest. Early marketing efforts for these fish will focus on the attributes of farmed halibut as an upscale seafood item. It will be sold, mostly in N. Europe, to white table cloth restaurants and high end retail outlets. It will be promoted as 'Atlantic' halibut and positioned as a gourmet item available year round and always in perfect condition.

As the salmon farming industry has shown, however, production can increase quickly once key technical hurdles have been overcome and if the species in question has what it takes to be a good farm fish. Halibut appears to have what it takes and both the main hurdles, namely juvenile production and on-growing in net pens, would seem to be susceptible to technical innovation. At some point in future, therefore, it is possible, even probable, that the halibut farming industry will take off. Whether this will be in 5,10,15 or 20 years is hard to say, but enough of the key elements are in place to suggest it will happen. When it does, the cost of producing farmed halibut will come down and so, most likely, will the price for which it is sold. Farmed, rather than wild, halibut could then become the grocery store staple, in the same way as farmed salmon is today.

At some point in this evolution, volumes of farmed halibut will exceed landings of wild Pacific halibut. Since seventy three million pounds[96] is not a huge amount of fish, compared, for example, with 1.5 billion pounds of farmed salmon which is now produced worldwide, this point could be reached quite quickly, perhaps by 2010. If and when this happens, an opportunity will then develop to market wild Pacific halibut differently. Instead of being the main line item, it could be positioned as a gourmet

[95] Montfort. M.C. 1998. Sea bass and sea bream production explodes in Europe. Seafood International. Vol. 13, No. 12, p 35-39.

[96] IHPC News Release. The recommended coast-wide commercial catch limit for 1999. 12.8.98.

product, differentiated on the basis of origin, size and other quality attributes, and now justifying a premium. Again, the salmon industry provides an analogy where the success of Copper River salmon, and now other labels of origin, are showing that, where there is a finite supply of a high quality wild fish, it can be turned to advantage in a market where the farmed product has become the principle commodity. Though the Pacific halibut fishery is relatively stable and well managed the supply is limited. It is not likely to yield harvest increases of hundreds of millions of pounds, as halibut farms are potentially capable of doing. With a limited supply of one of the world's highest quality wild fish, marketers of wild Pacific halibut would seem likely to be in a good position to make the most of premium marketing when the time comes.

Appendix 1
The Major Players

Organization	Activity
Norway - Public Sector Research	
Institute of Marine Research, Austevoll Aquaculture Research Station, N - 5392 Storebo	Principle government research facility developing all phases of halibut aquaculture
AKVAFORSK, Institute of Aquaculture Research AS, 6600 Sunndalsora	Research on juvenile and food fish nutrition and breeding / selection
University of Bergen, Institute of Fisheries and Marine Biology & Laboratory of Molecular Biology	Research on larval rearing, feeding and feeding behavior
Marintek - Sintef Group, Otto Nieserv., 10, N - 7002 Trondheim	Development of cages (net pens) for halibut Contract research
SINTEF, Center for Aquaculture, N - 7034, Trondheim	Research on larval rearing Fish quality
University of Tromso	Research on production in raceways
Norway - Commercial Activities	
Stolt Sea Farm, Nedre Slottsgate 15 0102 Oslo	The leading commercial producer both of juveniles and food fish
AMY AS Austevoll	Reported to be the second largest producer. Cooperates with Maritime Mariculture in E. Canada
Felleskjopet Havbruk, 4335 Dirdal	Commercial grower
Norwegian Halibut Nord-Trondelag	Juvenile producer
Lofilab Vestvagoy	Juvenile producer
Davik Fiskeoppdret A/S	Egg and juvenile producer
Brema Settefisk, Svelgen	Pilot scale on-growing
Vest Marinfisk A/S, Bergen	Start-up on-growing
Troms Marine Yngel	
Naeroysund Yngelfarm	
Norway Marine Culture, Tjeldbergodden	
Akvaplan-niva N 9001, Tromso	Consulting and research services, shallow raceway and cage on growing of halibut.
Rolf Englesen AS	Consulting services

Organization	Activity
United Kingdom - Public Sector Research	
Sea Fish Industry Authority, Ardtoe, Scotland	Principal government research facility developing all phases of halibut aquaculture.
The Scottish Office Marine Lab, Aberdeen, Scotland	Research on nutrition and larval rearing
Stirling Institute of Aquaculture, Stirling, Scotland	Research on food fish nutrition
North Atlantic Fisheries College, Scalloway, Shetland	Commercial farming demonstration and training
British Halibut Association, Edinburgh, Scotland	Association of commercial hatcheries, growers, research institutes and feed companies
United Kingdom - Commercial Activities	
Marine Harvest McConnell, Edinburgh, Scotland	Leading commercial grower
Mannin Seafarms, Port Erin, Isle of Man	Hatchery and consulting services
Otter Ferry Salmon, Otter Ferry, Scotland	Producer of juveniles, food fish and contract R&D facility
Orkney Marine Hatcheries, Orkney, Scotland	Juvenile producer
Iceland - Commercial Activities	
Fiskeldi Eyjafjordar Ltd.,	Producer of juveniles and food fish
Ireland - Commercial Activities	
Eileabo Teo Oilean Chleire Cape Clear Island	On-growing
Turbard Iarthar Chonemara Teo	On-growing
Canada - Public Sector Research	
DFO Biological Station, St Andrews, NB	Broodstock development and hatchery rearing
Memorial University, Marine Science Research Lab., Newfoundland	Research on all phases of halibut rearing
Commercial - Activities	
Maritime Mariculture, St Andrews, NB	Producer of juveniles and food fish
Chile - Public Sector Research	
FONDEF	Broodstock development, juvenile and food fish production - assisted by Mannin Seafarms
Fundacion Chile	Research - all phases
University de Magellanes	Broodstock development
USA - Public Sector Research	
National Marine Fisheries Service Manchester, WA	Broodstock development and larval rearing (Pacific halibut)

Appendix 2
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